

CDF OXYGEN DEFICIENCY HAZARD ANALYSIS

CONTRIBUTORS:

1. Craig Drennan, June 8, 1992
2. Bruce Squires, 6-July-92
3. Paul Wheelwright, July 29, 1992, July 12, 1993
4. Bob Sanders, Larry Spires, Rich Schmitt, Pat Lukens, September, 1999/January, 2000

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1 INTRODUCTION

This Oxygen Deficiency Hazard (ODH) Risk Assessment for the Collider Detector Facility was prepared to meet the requirements of the Fermilab ES&H Standard[1]. A Fatality Rate for both the Assembly Hall and the Collision Hall is computed in order to determine the ODH Classification of each area. Throughout this document it will be assumed that the CDF is operating in its mode which presents the greatest challenge to its ODH status. Namely, we will consider the facility to be at full operation, with both the cryogenic and detector gas systems in operation. Partial operations (detector gas on but cryogenics off, etc.) will be considered to be covered by the full analysis, and to represent lower risks. The conclusions of this analysis will be that both the CDF assembly and collision halls represent ODH class 0 areas.

This document begins with a description of the building and gas systems. Significant differences between the assembly and collision halls will be explicitly stated where appropriate. The ventilation and ODH response systems will also be described. A second section will be devoted entirely to the calculation of fatality rates for the two areas. Detailed engineering calculations that are used in support of the fatality factors can be found in the appendices.

2 DESCRIPTION OF THE FACILITY

2.1 Building and Detector Parameters

The CDF building is equipped with ventilation, oxygen monitoring, and flammable gas monitoring systems. Table 1 is a summary of the volumes of the rooms and the ventilation provided.

Table 1 Room Volumes and Ventilation

Area		Volume(cu. ft.)	Ventilation(cfm)
Assembly Hall	High Bay	621,000	8,000
	Pit without detector	294,000	12,000
	Pit with detector	263,886	12,000
Collision Hall	Empty	146,981	34,000
	With detector installed	109,669	34,000
Test Rooms	Room 112	2,400	1,525
	Room 113	2,700	1,400
	Room 114	3,750	5,200

Appendix A itemizes these components with regard to their volumes.

2.2 The Ventilation Systems

In the event that large volumes of helium, nitrogen, or SUVA are released in the Assembly Hall or Collision Hall, it is essential to provide sufficient ventilation to remove the gases and provide fresh air. The following air handlers at CDF have emergency modes in which they respond to ODH conditions.

Table 2 Collision Hall Fans

Device	Flow (cfm)	Location	Emergency Power
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AC2	17,000	Supply Duct	
AC3	17,000	Supply Duct	✓
BF1	34,000	Supply Duct	
PFI	34,000	Return Duct	✓
EF1	450	Return Duct	✓

The collision hall fans are listed in Table 2. With the exception of EF1, these fans operate as recirculators, to maintain the environment of the collision hall. In the event of an ODH alarm, the system will configure its louvers to purge the hall. Upon detection of an ODH condition the recirculation louvers fully close and the outside air and exhaust louvers fully open providing for full air exchange. Additionally, EF1 provides a 450 CFM fan on the return duct which exhausts return air to the outside on a continuous basis.

Table 3 Assembly Hall Fans

Device	Flow (cfm)	Location	Emergency Power
AH1	12,000	Center	✓
AH2	8,000	East	
RE1	4,000	Ceiling	
RE2	4,000	Ceiling	
RE3	4,000	Ceiling	
RE4	4,000	Ceiling	
RE7	6,000	Ceiling	
Pit Purge	10,700	East Pit	✓
EF2	450	Weld Booth	✓

The assembly hall fans are listed in Table 3. AH1 and AH2 fan louvers operate in the same mode as the collision hall with one exception. The assembly hall delivers air to the pit in winter and the ceiling in summer. In the event of an ODH detection the supply air louver configures to the winter setting delivering air to the deep pit. In addition, an ODH condition in the lower pit of the assembly hall triggers the operation of the pit purge fan. ODH conditions in the ceiling cause the ceiling louvers configure to full open, and the corresponding fans RE1-RE7 operate. Additionally, a 450 CFM fan (EF2) in the east weld booth exhausts from the building when the detector is present and the COT inert flow has the potential to operate.

Exhaust fans EF1 and EF2 have their flow monitored, and an alarm is generated if a flow less than 350 cfm is found for a period of four hours. Consequently, a minimum ventilation of 350 cfm is available for fresh air exchange in the Assembly Hall Pit, the Assembly Hall High Bay and the Collision Hall areas. Leakage and infiltration will increase this fresh air rate. The ventilation for the Test Rooms is supplied from and returned to the Assembly Hall High Bay. Because of this, a release of non-oxygen gas into the Test Rooms is also considered to be released into the Assembly Hall and concentrated into the Pit Area. Emergency power is provided for all of the ventilation fans in the Assembly Hall and half of the ventilation fans in the Collision Hall. Therefore, during a power outage, the ventilation for both areas will continue to be normal.

2.3 ODH Condition Thresholds

Calculations of the ODH threshold conditions were made to determine the threshold values for instantaneous releases and continuous releases of oxygen displacing gases into the CDF Assembly Hall High Bay and Pit area, and the Collision Hall above which ODH conditions may exist. An ODH condition is considered possible if the oxygen concentration of the particular space can be reduced to 18%. Details of these calculations are described in Appendix B, and are summarized in Table 4.

Table 4 ODH Thresholds

Area	Instantaneous Release (cu. ft.)	Continuous Release (cfm)
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	Helium	Nitrogen	Helium	Nitrogen
Assembly Hall	88,800	37,735	2,055	58
Collision Hall	15,680	15,680	58	58

2.4 Oxygen Monitor System

In the Assembly Hall, there are two fixed oxygen sensors in the pit near the floor and two oxygen sensors at the ceiling in the high bay. In the Collision Hall, there are two oxygen sensors near the floor and two near the ceiling. Two more oxygen sensors are on the bottom of the central detector. There are no oxygen sensors in the Test Rooms. There are 10 oxygen sensors in total. The oxygen sensors that are low are for detecting a reduction in oxygen due to a release of gases (such as cold nitrogen) that are at least as dense as air. The ceiling sensors detect reductions due to a release of helium. The chassis for these oxygen sensors are in the Cryo Control Room Relay Rack #1.

The evacuation alarm is powered from a 4 hour UPS. Failure of this alarm is not considered credible. PF-1, AC-3, the exhaust fans, and the UPS are powered from the diesel generator bus.

2.5 Assembly Hall Pit Area Ventilation ODH Response

When one of the two sensors in the Assembly Hall Pit detect an oxygen concentration of 18% or less, warning horns and lights in the Assembly Hall and the Cryo Control Room are energized. Pneumatic pressure is removed from the actuators regulating the positions of the return air, outdoor air, and exhaust air dampers of air handler AH-1. This places them in their normal de-energized/ODH positions. The de-energized positions for these dampers, as well as their counterparts in the other air handlers, are shown in Table 5.

Table 5 Assembly Hall Damper ODH Response

Damper	ODH Response
AH-1, AH-2 Outdoor Air	Open
AH-1, AH-2 Return Air	Closed
AH-1, AH-2 Exhaust Air	Open
RE-1, RE-2, RE-3, RE-7	Open

When in these positions, AH-1 provides 12,000 cfm of fresh air into the Assembly Hall Pit. The AH-1 air handler also goes into its winter mode of operation where the supply air flows into the Pit Area near the southwest corner at approximately the 725 foot level. The return air duct for AH-1 is located in the southwest corner of the High Bay Area at the 766-foot level.

In addition to the AH-1 air handler, the Pit Purge Fan will turn on in order to exhaust 10,700 cfm of pit gas outside. The pit purge fan is located in the south-east corner of the Pit Area, at the 710-foot level, and starts to draw air out of the Pit Area to exhaust the air to the east side of the building. Both of these fans are provided emergency power during a power failure.

Finally, dampers on the roof exhaust vents, RE-1, RE-2, RE-3, and RE-4 open fully to their de-energized positions. Each roof exhaust vent provides an opening of four square feet.

2.5 Assembly Hall High Bay Area Ventilation ODH Response

When one of the two sensors in the Assembly Hall High Bay detect an oxygen concentration of 18% or less, warning horns and lights in the Cryo Control Room are energized. Pneumatic pressure is removed from the actuators regulating the positions of the return air, outdoor air, and exhaust air dampers of air handler AH-2. This places them in their de-energized/ODH positions as list in Table 5. When in these positions, AH-2 provides 8,000 cfm of fresh air into the High Bay. Air handler AH-2 also goes into its winter mode where the supply air is released into the High Bay at the far southeast end at approximately the 754-foot level. The return air duct is located directly above the supply duct at the 766-foot level. When the ceiling ODH detectors go into alarm, the roof exhaust dampers RE-1, RE-2, RE-3, RE-4, and RE-7 open fully

to their de-energized positions. Note however, at this time the fans for the roof exhausts do not start. The total opening provided by the roof exhaust vents is twenty (20) square feet.

2.6 Collision Hall Ventilation ODH Response

When one of the ODH oxygen sensors in the Collision Hall detects an oxygen concentration of 18% or less, warning horns and lights in the Collision Hall and the Cryo Control Room are energized. Pneumatic pressure to the return air, and outdoor air, and exhaust dampers is removed, placing them in their de-energized, purge positions. If the fans are off, they will be restarted automatically.

During a normal ODH response, the system of air handlers provides 34,000 cfm of air flow. Either BF1 or PF1 can provide at least 17,000 cfm of fresh air. When there is a power failure, AC-3 and PF-1 operate on emergency power and thereby only provide 17,000 cfm of fresh air. The supply air ducts are located on the West end of the Collision Hall, and the return ducts are located on the East end.

For the case when the shielding door is open, the Collision Hall and the Assembly Hall Pit are considered one area. In this case, an alarm in either area will cause the horns and lights in both areas to be energized, however, only the ventilation system in the area in alarm will respond to the alarm.

2.7 Significant Sources of Oxygen Displacing Gases

The significant sources of cryogenics and gases which could produce ODH conditions are listed in Table 6. These are considered the sources involved when analyzing the potential reduced oxygen hazard for the list of component failures or ruptures. Derivations of their flow rates are detailed in Appendix E.

Table 6 Summary of Oxygen Displacing Gases

Failure	Instantaneous Release (cu. ft.)		Continuous Release (cfm)		Reference
	Helium	N ₂ /SUVA	Helium	N ₂ /SUVA	
Clean Gas Header	0	0	931	0	E.4
Tevatron High Pressure Header	0	0	5744	0	E.2
N2 Dewar #18	0	0	0	3566	E.5
N2 Dewar #32	0	0	0	3544	E.6
Helium Dewar	0	0	581		E.2
Low β Magnets	13000	7200	1100	600	E.8, E.9
Solenoid	240	244			E.10
N2 Valves	0	0	0	231	E.7
Argon	0	22.6	0	22.6	E.11
Argon/CO ₂	0	52	0	52	E.11
Argon/ethane	0	7.56	0	7.56	E.11
COT Refrigerant	0	5744	0	1450	F.12

2.8 COT Endplate Cooling Refrigerant

Contribution to the ODH Hazard: The entire refrigerant circuit contains 5744 SCF of SUVA 410A. This fluid has a molecular weight of 72.58 with a vapor density of 0.19 lb./cubic foot at atmospheric conditions. During operation most of the SUVA will be in the piping between the west alcove and the central detector. During extended shutdown periods most of it will be in the west alcove storage vessel. There are no significant restrictions between various parts of the system, so we assume that should a leak occur the entire charge would be vented. If we consider the Suva to be mixed in the entire halls it is not a significant hazard. But due to its high molecular weight we will consider, as a worst case, mixing in the bottom five feet of either Hall.

The storage vessel relief valve exhausts into the Assembly Hall. The upper notch phase separator relief valve exhausts into the assembly hall when the detector is there. In the collision hall it exhausts into piping vented outdoors.

3 COMPUTATION OF THE FATALITY RATES

In this section, the fatality rate calculations will be demonstrated. Three different conditions have been considered. First, the ODH implications of standard operation, where no equipment fails will be considered. In CDF operations, this does not represent a trivial situation. The large flow of nitrogen used to inert the central tracking chamber has implications for the oxygen concentration of the environment around the detector. Secondly, the fatality rate will be calculated for a single component failure, such as a sudden release of gas, or a ventilation failure. Finally, we will consider the implications of two simultaneous failures.

3.1 ODH condition during normal operation

During normal operation of the detector, there is a continuous discharge of nitrogen into the area around the detector, due to the need to purge the central tracking chamber. This flow is 30 cfm or less. From the calculation outlined in Appendix D.2.2 and the flow of EF1 or EF2 (350 cfm), we get a minimum steady state oxygen concentration of 19.3%. This is above the threshold needed for ODH hazard consideration, so we conclude that no additional analysis is needed for the situation where the facility is operating normally.

3.2 ODH condition for a single failure

For the failure of some component of the gas delivery or ODH mitigation system, a fatality rate given by

$\phi = \sum_i \phi_i = \sum_i F_i * P_i$, where F_i is the fatality factor and P_i is the probability of each failure, must be calculated. The sum is performed over all failures that might impact the ODH condition of the assembly or collision halls. The probability of fan failure is taken to be $3.07 \times 10^{-3} \text{ hr}^{-1}$, which is the sum of failure modes listed in

Table 7. The probability of failure for the ODH mitigation system is taken to be $2.3 \times 10^{-5} \text{ hr}^{-1}$, and is summarized in Table 8.

If the failure that occurs is in the ODH detection and response system, and no additional hazards are present, and the fatality factor is taken to be 0. We assume that the length of time needed to reach an ODH condition (calculated in sections B.3 and B.4) is long enough to treat this fatality factor as 0, since the fan failure will be detected and repair measures taken on a time scale that is short with respect to the decline in oxygen concentration.

Table 7 Failure Modes of the Ventilation System

Failure Mode	Probability(10^{-3} hr^{-1})
Electric Motors failure to run	0.01
Electrical power failure(1×10^{-4} demand-hr $^{-1}$)	0.003
Diesel Engine failure to start(3×10^{-2} demand $^{-1}$)	-
APACs Processor failure	1.4×10^{-10}
APACs I/O Module failure	3×10^{-4}
Irresponsible Program changes	0.011
Programming Mistakes	0.02
Hackers changing the control program	0.007

ODH Controller Hardware failure	0.01
Operator Bypass Key (human error)	0.01
Generator failure (outside power)	1.0
Actuator(s) failure	1.0
Fan(s) failure	1.0
UPS Backup failure	0.01
Total	3.1

Table 8 Failure Modes of the ODH Detection and Reaction System

Failure Mode	Probability(10^{-3} hr^{-1})
Detection system failure rate [3]	0.01
Vent fails to operate ($1 \times 10^{-2} \text{ demand-hr}^{-1}$) x ($1 \times 10^{-3} \text{ demand}^{-1}$)	0.01
Actuator fails to operate ($1 \times 10^{-2} \text{ demand-hr}^{-1}$) x ($3 \times 10^{-4} \text{ demand}^{-1}$)	0.003
Total	0.023

The fatality factors and probabilities of occurrence for the events that could generate an ODH condition in the assembly and collision halls are detailed in Appendices F and G. A summary of these factors along with the reference to its derivation is given in Table 9. The various failure modes are labeled according to the section of their description in the appendices.

Table 9 Fatality Factors and Probabilities for a Single Failure

Assembly Hall				Collision Hall			
Failure	Fatality	Prob.(hr ⁻¹)	φ _i (hr ⁻¹)	Failure	Fatality	Prob.(hr ⁻¹)	φ _i (hr ⁻¹)
ODH System	0	2.30E-05	0.00E+00	ODH System	0	2.30E-05	0.00E+00
Ventilation	0	3.10E-03	0.00E+00	Ventilation	6.00E-08	3.10E-03	1.86E-10
App. F.1	3.00E-02	1.30E-08	3.90E-10	App. G.1	0.00E+00	1.00E-05	0.00E+00
App. F.2	2.00E-06	9.80E-06	1.96E-11	App. G.2	0.00E+00	6.60E-06	0.00E+00
App. F.3	2.00E-06	1.00E-05	2.00E-11	App. G.3	0.00E+00	6.00E-06	0.00E+00
App. F.4	0	1.00E-11	0.00E+00	App. G.4	0	4.00E-06	0.00E+00
App. F.5	0	3.00E-06	0.00E+00	App. G.5	0	4.00E-09	0.00E+00
App. F.6	1.00E-07	4.00E-05	4.00E-12	App. G.6	0	1.50E-08	0.00E+00
App. F.7	0	3.28E-05	0.00E+00	App. G.7	0	1.00E-07	0.00E+00
App. F.8	6.00E-05	3.00E-06	1.80E-10				0.00E+00
App. F.9	6.00E-05	3.00E-06	1.80E-10				0.00E+00
App. F.10	0	1.68E-05	0.00E+00				0.00E+00
App. F.11	0	1.50E-08	0.00E+00				
App. F.12	0.00E+00	2.00E-05	0.00E+00				
φ(hr ⁻¹) total			7.94E-10	φ(hr ⁻¹) total			1.86E-10

The sum over failures for the two areas is listed at the end of Table 9, and is well below the ODH class 0 threshold. We conclude that a single failure of the facility does not impact our ODH status.

3.3 ODH condition for two simultaneous failures

A more complicated situation exists for simultaneous failures. We will consider the situation of simultaneous failures of the gas/cryogen delivery systems, and ODH mitigation systems (ODH alarm and ventilation). For this situation, the fatality rate calculation becomes

$$\phi = \begin{bmatrix} P_{He-1} & P_{He-2} & \dots & \dots \end{bmatrix} \begin{bmatrix} F_{He-1,ODH} & F_{He-1,Fans} \\ F_{He-2,ODH} & F_{He-2,Fans} \\ \vdots & \vdots \\ \vdots & \vdots \end{bmatrix} \begin{bmatrix} P_{ODH} \\ P_{Fans} \end{bmatrix}, \text{ where the factors } P_i \text{ correspond to the probability of failure}$$

mode i , and the factors $F_{i,ODH}$, $F_{i,Fans}$ are the fatality factors due to failure i , for ODH alarm and ventilation failures respectively. The fatality factors and probabilities used are derived in Appendices F and G, and summarized in Table 10. The various failure modes are labeled according to the section of their description in the appendices.

Table 10 Fatality Factors and Probabilities for a Double Failure

Assembly Hall					Collision Hall				
Failure	Prob.(hr ⁻¹)	Fatality factor		ϕ_i (hr ⁻¹)	Failure	Prob.(hr ⁻¹)	Fatality factor		ϕ_i (hr ⁻¹)
		ODH	Fans				ODH	Fans	
App. F.1	1.30E-08	1	3.00E-02	1.51E-12	App. G.1	1.00E-05	1	1.00E+00	3.12E-08
App. F.2	9.80E-06	1	2.00E-06	2.25E-10	App. G.2	6.60E-06	1	1.00E+00	2.06E-08
App. F.3	1.00E-05	1	2.00E-06	2.30E-10	App. G.3	6.00E-06	1	1.00E+00	1.87E-08
App. F.4	1.00E-11	1	0	2.30E-16	App. G.4	4.00E-06	1	1	1.25E-08
App. F.5	3.00E-06	1	0	6.90E-11	App. G.5	4.00E-09	1	1	1.25E-11
App. F.6	4.00E-05	1	1.00E-07	9.20E-10	App. G.6	1.50E-08	1	1.00E+00	4.68E-11
App. F.7	3.28E-05	1	0	7.54E-10	App. G.7	1.00E-07	1	1	3.12E-10
App. F.8	3.00E-06	1	1	9.37E-09					
App. F.9	3.00E-06	1	1	9.37E-09					
App. F.10	1.68E-05	1	1	5.25E-08					
App. F.11	1.50E-08	1	1.00E+00	4.68E-11					
App. F.12	2.00E-05	6.50E-04	6.50E-04	4.06E-11					
ϕ (hr ⁻¹) total				7.35E-08	ϕ (hr ⁻¹) total				8.34E-08

3.4 Recommendations and Conclusions

Table 11 lists the breakdown for the ODH classifications[1]. Under normal operating conditions, the fatality rates calculated for the CDF Assembly Hall pit, Collision Hall, and test rooms satisfy the criterion for ODH class 0 status.

Table 11 ODH Classifications

ODH Class	Fatality Rate Range
0	$\phi < 1\text{E-}7$
1	$1\text{E-}7 < \phi < 1\text{E-}5$
2	$1\text{E-}5 < \phi < 1\text{E-}3$

For the condition where the normal ventilation is turned off or fails, these areas will acquire an ODH class 2 status when the cryogenic and gas systems are fully operational. This analysis does not consider the Cryo Control Room to have ventilation and the Fatality Rate is determined to be 1 E-9 fatalities per hour. Therefore, the Cryo Control Room will remain ODH 0. For the Test Rooms, before any instrument/detector is tested, an ODH analysis should be performed in order to determine if the possible volume releases or other failures will cause an increase in the ODH classification.

APPENDIX A. VOLUME OF THE CDF DETECTOR AND ASSOCIATED COMPONENTS

The following lists the components of the CDF detector and their approximate volumes. This information is used in determining the volume of air available in the Assembly Hall Pit area and the Collision Hall.

<u>Item</u>	<u>Unit Volume(cu. ft.)</u>	<u>Sub Totals(cu. ft.)</u>
Central Muon Upgrade (CMUP)		
Steel	1253	2508
North and South Chambers	221	422
Yoke Top and Bottom Chambers	177	254
CMUP Lower Elevation 706-710		
Steel	270	540
Support Stand	16	32
1.5" Steel Plate	16	32
Chambers	34	68
Pit Bridge		
Blocks (10 pieces	330	660
2" Steel Plate	25	50
Yoke, Plug, Cryostat and electronics	5650	5650
End Wall Hadron (48 units)	38	1824
Transfer line (Cryo)	19	19
Central Muon Extensions	242	968
Central Arch Assemblies	1243	4972
Toroids (25 foot diameter)	3355	6710
Electromagnetic Calorimeters	262	524
Hadronic Calorimeters	1470	2940
Central Tracking Chamber	7919	7919
Main Beam Bypass Shielding	1200	1200
Total Volume of components		37,312

- Data on volumes provided by John Rauch, TS/Engineering.

Appendix B. ODH condition Threshold Calculations

B.1 Instantaneous release of helium into Assembly Hall or Collision Hall area

It is assumed that helium released will be released above the top level of the Pit Area and that the helium will be of sufficiently low density that it will not drop down into the Pit area. Therefore, only the volume of the Assembly Hall High Bay area is considered in the following calculation.

For C_o = Concentration of oxygen, C_h = Concentration of helium, C_a = Concentration of air.

We have that

$$\begin{aligned} C_o &= 0.21 * C_a \\ C_a &= 1 - C_h, \text{ therefore } C_o = 0.21 * (1 - C_h) \end{aligned}$$

In order to maintain the concentration of oxygen above 18%, the concentration of helium must remain below 14.3%.

Given that the volume of the Assembly Hall High Bay area has a volume of 621,000 cubic feet, the instantaneous release of helium must remain below 88,800 cubic feet.

Given that the volume of the Collision Hall area has a volume of 109,669 cubic feet, the instantaneous release of helium must remain below 15,680 cubic feet.

B.2 Continuous release of helium into the Assembly Hall area.

In calculating the continuous release of helium into the High Bay area the roof exhaust dampers of RE-1, RE-2, RE-3, RE-4, and RE-7 are considered to be open in their fail-safe position. These dampers will be in this position whenever power has been removed from the air handler AH-2 or when the ceiling ODH detectors detect an ODH condition.

The method outlined in Appendix C is used to compute the maximum allowable rate of helium flow into the High Bay area given the maximum acceptable steady state concentration of helium and the building height, h , and vent area, A .

$$C_h^3 + C * C_h - 1.16 * C = 0 \quad (4)$$

where

$$\begin{aligned} C &= 144 * (0.0001617) * I^2 / (32.2 * h * A^2) \\ &= 144 * (32.2) * (0.0001617) * 12 / (32.2 * 35 * 400) \\ &= 1.66 * 10^{-6} * I^2 \end{aligned} \quad (5)$$

Rearranging the cubic equation and plugging in for C , we have

$$I^2 = C_h^3 / [1.66 * 10^{-6} * (1 - C_h)]$$

Given a maximum allowable $C_h = 0.143$, the continuous rate of helium flow threshold is

$$I = 47 \text{ scfs} = 2,055 \text{ scfm.}$$

B.3 Continuous release of helium or nitrogen into the Assembly Hall that remains undetected by the ODH detection system.

This threshold value applies to the condition where the roof exhaust dampers remain closed because the air handler is operating and the ODH system does not indicate an ODH condition. For this situation we consider the normal introduction of outdoor air into the air handling system.

Fresh air to the assembly hall is assured by the operation of EF2, which generates an evacuation alarm if its flow falls below 350 scfm. The maximum allowable flow of helium or nitrogen into the Assembly Hall can be determined by the method outlined in Appendix D (section D.2.2). If we take the exhaust flow from the area to be 350 scfm, we

obtain $R = \left(\frac{0.21}{C(\infty)} - 1 \right) * Q = 58 \text{ scfm}$. This implies that the normal ventilation system will accommodate up to 58 scfm of helium and nitrogen (and carbon dioxide) leakage in this normal operating mode.

The oxygen concentration in the event of complete fan failure will fall due to the tracking chamber purge. The impact of this can be calculated by the method in Appendix D (section D.2.3). If we assume an initial oxygen concentration of 21%, and a purge rate (R) of 30 cfm, the time to reach an ODH condition is then $t = \frac{-V}{R} \ln\left(\frac{0.18}{0.21}\right)$, which is 1350 minutes in the assembly hall pit.

B.4 Continuous release of helium or nitrogen into the Collision Hall area that remains undetected by the ODH detection system.

Fresh air to the collision hall is assured by the operation of EF1, which generates an evacuation alarm if its flow falls below 350 scfm. Using the method in Section D.2.2, we can allow a constant flow of 58 scfm of non-oxygen gases into the Collision Hall. The time to reach an ODH condition due to the nitrogen purge and complete fan failure will be 560 minutes in the collision hall.

B.5 Instantaneous release of nitrogen into the Assembly Hall.

Any release of nitrogen is considered to be of sufficiently high density so as to flow down into the Pit area of the Assembly Hall. Therefore, only the volume of the Pit area will be considered. The volume of the Pit area when the detector is not in the Pit area is 294,000 cubic feet. Therefore, the instantaneous release of nitrogen must remain below 42,000 scf. The volume of the Pit area when the detector is there is approximately 263,886 cubic feet. Therefore, the instantaneous release of nitrogen must remain below 37,735 scf.

B.6 Instantaneous release of nitrogen into the Collision Hall.

The volume of the Collision Hall when the detector is in place is 109,669 cubic feet. Therefore, the instantaneous release of nitrogen into the Collision Hall must remain below 15,680 scf.

B.7. Summary:

A. Assembly Hall

- i) Instantaneous helium release threshold = 88,800 scf
- ii) Instantaneous nitrogen release threshold = 37,735 scf
- iii) Continuous helium flow threshold = 2,055 scfm (roof exhaust dampers open)
- iv) Continuous helium or nitrogen flow threshold = 58 scfm (normal operation)

B. Collision Hall

- i) Instantaneous helium release threshold = 15,680 scf
- ii) Instantaneous nitrogen release threshold = 15,680 scf
- iii) Continuous helium or nitrogen flow threshold = 58 scfm

APPENDIX C. CONCENTRATION OF HELIUM IN THE ASSEMBLY HALL HIGH BAY AREA

The calculations in this appendix are based on a portion of the report, "Oxygen Deficiency Hazard Classification of the P1 Service Building", by P.O. Mazur, February 18, 1983. We wish to find the steady state concentration of helium in a room with roof exhaust openings and a steady flow of helium into the room. Define the fraction of helium in the air-helium mixture being vented to the outside of the building as x and the fraction of air as (1 - x). The density of the mixture is then

$$\rho(\text{mixture}) = x \cdot \rho(\text{He}) + (1 - x) \cdot \rho(\text{air})$$

The difference between the densities of air and of this mixture is

$$\Delta\rho = \rho(\text{air}) - \rho(\text{mixture}) = x \cdot [\rho(\text{air}) - \rho(\text{He})]$$

The driving force per unit area (i.e. the pressure) available for a column of this mixture of height h is

$$\Delta P = \Delta\rho \cdot (g / gc) \cdot h \text{ (lbf / ft}^3\text{)} = \Delta\rho \cdot (g / gc) \cdot h / 144 \text{ (psi)}$$

Where

$$\begin{aligned} g &= 32.2 \text{ ft / s}^2 \\ gc &= 32.2 \text{ (lbm} \cdot \text{ft) / (lbf} \cdot \text{s}^2\text{)} \\ h &= \text{height in ft.} \\ \Delta\rho &= \text{difference in density in lbf / ft}^3 \end{aligned}$$

Define the helium release rate to be I, in scfs. The helium vent rate must also be I and the total vent rate is I / x. For a hole of area A, the vent flow must have a velocity of $V = I / (A \cdot x)$.

From Crane Technical Paper No. 410, Equation 3-14,

$$\Delta P = 0.0001078 \cdot K \cdot \rho \cdot V^2$$

where K can be chosen conservatively as 1.5 from Equation 2-9 and Equation 2-10. For convenience define

$$K1 = 0.0001078 \cdot K = 0.0001617$$

We now have

$$\Delta P = K1 \cdot \rho \cdot V^2 = \rho \cdot (g / gc) \cdot h / 144$$

We can now write an equation for the equilibrium helium fraction x in terms of the building parameters A and h and the helium release I.

$$\Delta P = K1 \cdot [x \cdot \rho(\text{He}) + (1 - x) \rho(\text{air})] \cdot (I / (A \cdot x))^2 = x \cdot [\rho(\text{air}) - \rho(\text{He})] \cdot (g / gc) \cdot h / 144$$

or

$$(144 \cdot gc \cdot K1 \cdot I^2) / (g \cdot h \cdot A^2) \cdot [x \cdot \rho(\text{He}) + (1 - x) \rho(\text{air})] = x^3 \cdot [\rho(\text{air}) - \rho(\text{He})]$$

Defining $C = 144 \cdot gc \cdot K1 \cdot I^2 / (g \cdot h \cdot A^2)$ we get

$$x^3 + C \cdot x - C \cdot \rho(\text{air}) / [\rho(\text{air}) - \rho(\text{He})] = 0$$

By substituting in the densities of air and helium this becomes

$$x^3 + C \cdot x - C \cdot 1.16 = 0$$

The solution to this cubic equation is

$$x = C^{(1/3)} * \{ [0.58 + (C/27 + .3364)^{(1/2)}]^{(1/3)} + [0.58 - (C/27 + .3364)^{(1/2)}]^{(1/3)} \}$$

APPENDIX D. COMPUTATIONAL METHODS USED

D.1 METHODS USED FOR DETERMINING FLOW RATES

D.1.1 METHOD I

Crane Technical Paper 410. Compressible Flow in Pipe, Equation 1-11, page 1-9.

This method was used when the piping leading from the source of cryogenics to the building was considered to be a major restriction to flow.

$$V1 = 1 / \rho_{g1} \quad \text{"V1 should be in units of ft}^3/\text{lb"}$$

$$w = 0.525 * Y * D^2 * \sqrt{(p1 - p2) / (K * V1)}$$

$$q = (w / \rho_{g2}) * 60$$

<u>Var.</u>	<u>Units</u>	<u>Description</u>
w	lb/s	Mass flow rate
q	scfm	Mass flow rate
d	in	Inside diameter of pipe
p1	psig	Inlet pressure
p2	psig	Outlet pressure
Y	--	Net expansion factor Crane A-22
Py	--	(p1-p2)/p1, used to determine Y
K	--	Resistance coefficient
ρ_{g1}	lb/ft ³	Density of the gas at inlet condition
ρ_{g2}	lb/ft ³	Density of the gas at outlet condition

Here the resistance coefficient, K, is determined as follows:

i) For pipe of length L (ft) and diameter d (in)

f_T -> selected from the table on page A-26.

$$K_i = f_T * L / (d / 12)$$

$$K_i = K_i * (D / d)^4 \quad \text{"Convert to working diameter"}$$

ii) For valves of diameter d (in) and flow coefficient Cv

$$K_i = (29.9 * d^2 / C_v)^2$$

$$K_i = K_i * (D / d)^4 \quad \text{"Convert to working diameter"}$$

iii) For long radius elbows.

f_T -> selected from the table on page A-26.

$$90 \text{ deg} \rightarrow K_i = 14 * f_T$$

$$45 \text{ deg} \rightarrow K_i = 9.91 * f_T$$

The total resistance coefficient is taken as $K = \sum K_i$

D.1.2 METHOD II

ISA Standard ISA-575.01-1985, Chapter 6 Compressible Fluid - Flow of Gas and Vapor, Equation 18, page 14.

This method was used when considering the flow through only a valve with a known flow coefficient and given inlet and outlet pressures. It generally gives a smaller value of flow than using the Crane 410 method for determining flow through a valve, but is considered to be more accurate.

$$pr = p1 / pc$$

$$Tr = T1 / Tc$$

$$F_k = c_p / c_v / 1.4 \quad \text{"Ratio of specific heats factor"}$$

$$G_g = M / Ma \quad \text{"Gas specific gravity at standard conditions"}$$

$$x = (p1 - p2) / p1$$

$$\text{IF } x \leq (F_k * x_T) \text{ THEN } Y = 1 - x / (3 * F_k * x_T)$$

$$\text{IF } x > (F_k * x_T) \text{ THEN } Y = 2 / 3$$

$$q = N_7 * F_p * C_v * p1 * Y * \text{sqrt}(x / (G_g * T1 * Z))$$

$$Q = q * (60 / 0.0283)$$

<u>Var.</u>	<u>Units</u>	<u>Description</u>
q	m ³ h	Volumetric flow a~ outlet conditions
Q	scfm	Mass flow rate
p1	bar	Upstream Pressure
p2	bar	Downstream Pressure
pc	bar	Critical Pressure
T1	degK	Upstream Temperature
Tc	degk	Critical Pressure
Tr	--	Reduced Temperature used to determine Z
pr	--	Reduced Pressure used to determine Z
Z	--	Z-factor for ideal gas assumption
Cv	--	Valve flow coefficient
M	--	Molecular weight of flowing gas
Ma	--	Molecular weight of air
c _p	KJ / Kg.K	Specific Heat at constant pressure
c _v	KJ / Kg.K	Specific Heat at constant volume
x _T	--	Pressure drop ratio factor App. D.
N ₇	--	Numerical constant pg. 14
F _p	--	Piping geometry factor

D.1.3 METHOD III

ISA Standard ISA-575.01-1985, Chapter 5 Incompressible Fluid - Choked Flow of Vaporizing Liquid, page 12.

This method was used when considering the flow of liquid cryogenics through a valve.

$$F_f = 0.96 - 0.28 * \text{sqrt}(pv / pc) \quad \text{"Liquid critical pressure ratio factor"}$$

$$p_{vc} = F_f * p_v \quad \text{"Apparent absolute pressure at vena contracta"}$$

$$G_f = \rho_l / \rho_{h20} \quad \text{"Liquid specific gravity at upstream conditions"}$$

$$q_{\max} = N_1 * F_L * C_v * \sqrt{(p_1 - p_{vc}) / G_f}$$

$$q_{\text{out}} = (\rho_l / \rho_g) * q_{\max} * (60 / 0.0283)$$

Var.	Units	Description
q _{max}	m ³ /h	Max. Volumetric Flow at the upstream condition (choked flow conditions).
q _{out}	scfm	Max. Volumetric Flow at outlet conditions (1 atm. 300 degK)
C _v	--	valve flow coefficient.
p ₁	bar	Upstream absolute static pressure
p _c	bar	Abs Thermodynamic critical pressure
p _v	bar	Absolute vapor pressure of liquid at inlet temperature
_l	Kg/m ³	Density of liquid at flowing temperature
_h20	Kg/m ³	Density of water at 60 degrees F
_g	Kg/m ³	Density of gas at outlet conditions
N ₁	--	Numerical constant from Table 1, page 10
FL	--	Liquid Pressure recovery factor of a valve without attached fittings

D.1.4 METHOD IV

"Principle and Practice of Flow Meter Engineering", by L.K. Spink, The Foxboro Company, Foxboro Mass. provides the following method for determining the choked flow through an orifice. The method can be found in Chapter 19, page 382.

$$_l = M * p_{f1} * 144 / R / T / Z$$

$$_l = _l * g / g_c$$

$$\beta = D_o / D, \quad \text{determine } K_o \quad (\text{Eq'n 128})$$

$$K_{o1} = 0.5925 + 0.0182 / D + (0.440 - 0.06 / D) * \beta^2$$

$$\text{If } \beta > 0.25 \text{ Then Term1} = 0 \text{ else Term1} = (0.25 - \beta)^{2.5}$$

$$K_{o2} = (0.935 + 0.225 / D) * \beta^5 + 1.35 * \beta^{14} + 1.43 / \sqrt{D} * \text{Term1}$$

$$K_{od} = 1 + 0.000015 * (905 - 5000 * \beta + 9000 * \beta^2 - 4200 * \beta^3 + 875 / D)$$

$$K_o = (K_{o1} + K_{o2}) / K_{od}$$

$$S_p = K_o * \beta^2 \quad \text{"Noted in Ch. 19"}$$

$$Y_t = 3.25 \quad (\text{Estimated from Fig. B-2526, page 385})$$

$$W = 359 * Y_t * S_p * D^2 * F_a * \sqrt{\gamma_1 * P_{f1}}$$

$$\text{Critical (Choked) Flow (DP} > 0.5 * p_{f1}) \quad \text{"Eq'n 56"}$$

Var.	Units	Description
W	lbm / hr	Mass Flow Rate (Eq'n 56)
p _{f1}	psia	Pressure Upstream
p ₁	lbm / ft ³	Density Upstream
γ ₁	lbf / ft ³	Specific weight at upstream condition
D _o	in	Diameter of orifice

D	in	Diameter of Pipe
B	--	Diameter Ratio
Ko	--	Constant
Yt	--	Expansion Factor for 50% pressure dro
Fa	--	Factor for temperature expansion
Sp	--	$=K_o \cdot B^2$
T	deg R	Temperature
Z	--	Compressibility Factor
M	--	Molecular Weight
R	ft*lb / lb	Gas Constant
g	ft/s ²	Local Gravity
gc	lbm*ft / lb	Gravitational Constant

D.1.5 METHOD V

This method converts the flow of air through a rated relief device to the flow of helium for that device. It is normally used when sizing relief devices for liquid helium containers. For our purposes, we consider the maximum expected flow of helium through a relief valve to be that which corresponds to the rated flow of air for the device.

$$W = [Q_a \cdot 60 \cdot (0.01039 \cdot C / C_a)] \cdot \text{sqrt} [(M \cdot Z_a \cdot T_a) / (M_a \cdot Z \cdot T)]$$

<u>Var.</u>	<u>Units</u>	<u>Description</u>
W	lbm / hr	Mass flow rate of helium
Q _a	scfm	Rated flow of the relief valve
C	--	Gas constant of gas = 378 for helium
M	--	Molecular weight of gas = 4.003 for helium
T	deg R	Temperature of gas at flowing conditions
Z	--	Compressibility for the gas at flowing conditions
C _a	--	Gas constant of gas = 356 for air
M _a	--	Molecular weight of gas = 28.97 for air
T _a	deg R	Temperature of air at STP = 520 deg R
Z _a	--	Compressibility factor = 1.0 for air at STP

D.2 METHODS USED FOR DETERMINING OXYGEN CONCENTRATIONS GIVEN THE STEADY FLOW HELIUM OR NITROGEN INTO A VENTILATED AREA

The following two methods were those used for determining the time varying and steady state concentrations of oxygen in an enclosed space. This is considering the case in which helium or nitrogen is flowing into the space at a constant rate, and there exists some form of ventilation which is either supplying fresh air or exhausting the gas/air mixture.

Define the following variables with all flows in scfm.

Q _{in}	The total flow into the space
Q _{out}	The total flow out of the space
q _E	The flow of air exhausted out of the space at a constant rate
q _F	The flow of air supplied into the space at a constant rate
q _{air}	The flow of air into the space
q _{gas}	The flow of helium or nitrogen into the space
q _{o,in}	The flow of oxygen into the space
q _{o,out}	The flow of oxygen out of the space
V	The volume of the space
c(t)	The fraction of oxygen in the space

In each method we have the following relationships:

$$\begin{aligned}
\text{Total flow into the space:} \quad Q_{in} &= q_{air} + q_{gas} \\
\text{Flow of oxygen into the space:} \quad q_{o,in} &= 0.21 * q_{air} \\
\text{Flow of oxygen out of the space:} \quad q_{o,out} &= c(t) * Q_{out} \\
\text{The mass balance for the oxygen:} \quad d(V * c(t)) / dt &= q_{o,in} - q_{o,out} \\
d(V * c(t)) / dt &= 0.21 * q_{air} - c(t) * Q_{out}
\end{aligned}$$

D.2.1 METHOD VI

Here we consider the case where the ventilation system forces air into the space at a constant rate. For this situation we have

$$\begin{aligned}
q_{air} &= q_F \\
Q_{out} &= q_F + q_{gas}
\end{aligned}$$

That is, the total flow of air in is determined by the ventilation system and the total flow out of the space is equal to the sum of the air flow in plus the helium or nitrogen flow in. The mass balance for oxygen becomes,

$$d(V * c(t)) / dt = 0.21 * q_{air} - c(t) * Q_{out} = 0.21 * q_F - c(t) * (q_F + q_{gas})$$

If we consider the flow of helium or nitrogen into the space constant with respect to time from the time $t_0 = 0$, and consider the ventilation constant with respect to time, the solution to the mass balance is

$$\begin{aligned}
c(t) = \exp\{ - (q_F + q_{gas}) * t / V \} * (c(0) - 0.21 * q_F / (q_F + q_{gas})) \\
+ 0.21 * q_F / (q_F + q_{gas})
\end{aligned}$$

where $c(0)$ is the initial concentration of oxygen at time $t = 0$. This initial concentration is determined after allowing for instantaneous releases due to the failure under consideration. The steady state concentration of oxygen is found as we let $t \rightarrow \infty$.

$$c(\infty) = 0.21 * q_F / (q_F + q_{gas})$$

D.2.2 METHOD VII

Here we consider the case where an exhaust fan or return air fan draws the gas/air mixture from the space at a constant rate. For this situation we have

$$\begin{aligned}
Q_{out} &= q_E \\
q_{air} &= q_E - q_{gas}
\end{aligned}$$

That is, the total flow out of the space is determined by the exhaust or return air system and the total flow of air in is equal to the difference between the flow of gas/air mixture out of the space and the flow of gas (helium or nitrogen) into the space. The mass balance for the oxygen becomes,

$$d(V * c(t)) / dt = 0.21 * q_{air} - c(t) * Q_{out} = 0.21 * (q_E - q_{gas}) - c(t) * q_E$$

If we consider the flow of helium or nitrogen into the space constant with respect to time from the time $t_0 = 0$, and consider the flow of the gas/air mixture out of the space constant with respect to time, the solution to the mass balance is

$$c(t) = \exp\{ - q_E * t / V \} * (c(0) - 0.21 * (q_E - q_{gas}) / q_E) + 0.21 * (q_E - q_{gas}) / q_E$$

where $c(0)$ is the initial concentration of oxygen at time $t = 0$. This initial concentration is determined after allowing for instantaneous releases due to the failure under consideration. The steady state concentration of oxygen is found as we let $t \rightarrow \infty$

$$c(\infty) = 0.21 * (q_E - q_{\text{gas}}) / q_E$$

D.2.3 METHOD VIII

Here we consider the case where the air handling systems are off-line. When the air handling system is off-line, any continuous release of cryogens could pose a problem given enough time.

For the case of a helium release in the Assembly Hall, if the ODH detection system detects an ODH condition, the dampers on the roof exhaust fan will open. The ventilation provided by the roof exhaust is not considered when determining the time it takes to reach ODH conditions after a release.

Therefore, how long it would take to reach an ODH condition given the particular release rate of non-oxygen gas and the volume of the space. The equation used to calculate this time is taken from Method VI, where q_F is set to zero.

$$c(t) = \exp\{-q_{\text{gas}} * t / V\} * c(0)$$

To determine the time t^* , in minutes, when the oxygen concentration reaches 18% we use

$$t^* = -(V/q_{\text{gas}}) * \ln(0.18 / c(0))$$

The initial oxygen concentration is assumed to be 21% unless there is some instantaneous release involved with the type failure under consideration.

APPENDIX E. FLOW RATE CALCULATIONS

Listed below are the possible failures which would result in the release of helium or nitrogen into the CDF Assembly Hall or Collision Hall. A conservative estimate of the release rates that result from each failure was computed using one of the methods outlined in Appendix D. The units for each value used in the computations were those units called for by the particular method used. The failures considered are as follows:

E.1 Rupture of the compressor discharge line at the point that it enters the CDF Assembly Building, with Valve BAMV-5-H open connecting the CDF compressor discharge line to the clean gas header.

Method I, Appendix D was used to determine the maximum flow of helium gas into the CDF Assembly Hall given this event. The parameters used in the calculation and the results were as follows:

<u>Variable</u>	<u>Value</u>	<u>Units</u>
w	3.442	lb/s
q	20334	scfm
D	2.157	in
p1	285	psig
p2	0	psig
Y	.71	--
P _y	.951	--
K	14.059	--
pg1	3.18	Kg/m ³
pg2	.1625	Kg/m ³

The resistance coefficient, K, was computed for the piping that runs from the B0 Compressor building, over the beam, to the CDF Assembly Hall. This consisted of:

109 ft. of 2 in. straight pipe
6 ea. 2 in. 90 degree elbows
5 ea. 2 in. 45 degree elbows

Note: With valve BAMV-5-H closed connecting only the one CDF compressor to the discharge header the maximum flow rate would be that for the helium screw compressor. This is 57 grams /s or 713 scfm.

E.2 Rupture in the high pressure side of the heat exchanger, expansion engine U-tubes, or the valve box with valve BAMV-5-H open connecting the CDF compressor discharge line to the clean gas header.

Method IV, Section D.4 was used to determine the maximum flow of helium gas into the CDF Assembly Hall given this event. The major restriction to flow was considered to be the orifice of the flow indicator, FI4. The parameters used in the calculation and the results were as follows:

<u>Variable</u>	<u>Value</u>	<u>Units</u>
W	3,491	lbm / h
q	5,744	scfm
pf1	300	psia
p1	0.2073	lbm / ft ³
y1	0.2073	lb/ft ³
Do	0.7400	in
D	1.6820	in
B	0.4400	--
Ko	0.6929	--

Yt	3.2500	--
Fa	1	--
Sp	0.1341	--
T	520	deg R
Z	1	--
M	4.003	--
R	1545	ft. * lbf / lb
g	32.2	ft. / s ²
gc	32.2	lbm * ft. / lb

We find that the maximum expected flow rate for this failure is 3,491 lbm / h, which corresponds to 5,744 scfm.

E.3 Calculate the possible helium flow rate through either SV-257-H , SV-254-H, SV-1010-H, or SV-1602-H assuming the relief valve is stuck open. These relief valves are all rated for 100 scfm air flow. Method V of section D.5 will determine the maximum expected flow of helium for this failure. The parameters for the conversion from flow of air through the relief valve to the flow of helium are the following.

<u>Variable</u>	<u>Value</u>	<u>Units</u>
W	1,723	lbm / h
Qa	100	scfm
C	378	--
M	4.003	--
T	8.54	deg R
Z	0.67	--
Ca	356	--
Ma	28.97	--
Ta	520	deg R
Za	1	--

The flow of helium at 8.54 R is 234 lbm / h, which corresponds to 376.3 scfm.

E.4 The maximum flow rate into the rupture or leak in one of the following;

- i) The suction header
- ii) Low pressure side of the heat exchanger, or valve box.
- iii) (The Failure Rate is determined for the combination)
- iv) The transfer line helium return.
- v) Control dewar or rupture disk RD-1025-H
- vi) U-tubes HUT-2,6,10.
- vii) U-tubes HUT-1,8 (neglecting restriction to flow due to EVBY)
- viii) Relief valve sticks open. One of the following:
 - SV-1012-H SV-1013-H
 - SV-1011-H SV-1018-H

when the detector has a rupture or leak in any of the components of the low pressure side of the cryogenic system in the Assembly Hall or the Collision Hall could result in helium flow into the Assembly Hall from two sources. The first source is the helium storage dewar venting through control valve PVBP (Cv = 2). The second source is from the helium gas storage tanks through control valve PVLOSUC (Cv = 2). Method II of section D.2 is used to calculate the maximum flow through EVBP. The parameters used and the results are as follows:

<u>Variable</u>	<u>Value</u>	<u>Units</u>
Q	581	scfm
p1	1.565	bar
p2	1.0132557	bar
pc	2.2746	bar

(8 psig)

T1	4.744	degK
Tc	5.1953	degK
Tr	0.913	--
pr	0.688	--
Z	0.7	--
Cv	2	--
M	4.003	--
Ma	28.97	--
c _p	5.193	KJ/Kg.K
c _v	3.116	KJ/Kg.K
x _T	0.72	--
N ₇	417	--
F _p	1	--

Method II of section D.2 was also used to calculate the maximum flow from the Clean Gas Header through PVLOSUC.

<u>Variable</u>	<u>Value</u>	<u>Units</u>
Q	933	scfm
p1	250	psig
p2	1.0132557	bar
pc	2.2746	bar
Ti	280	degK
Tc	5.1953	degK
Tr	53.895	--
pr	8.024	--
Z	1	--
Cv	2	--
M	4.003	--
Ma	28.97	--
c _p	5.193	KJ/Kg.K
c _v	3.116	KJ/Kg.K
x _T	0.72	--
N ₇	417	--
F _p	1	--

The resulting maximum total flow from both sources, therefore, could be 1,514 scfm.

E.5. This section calculates the nitrogen flow rate into the CDF assembly hall assuming that the liquid nitrogen supply line ruptures at the point that it enters the CDF Assembly Building and Tank 18, the 13,000 gallon horizontal liquid nitrogen storage dewar is on line. Method I, Section D.1 was used to determine the maximum flow of nitrogen gas into the CDF Assembly Hall. The major restriction to flow was considered to be the piping that brings the liquid nitrogen from the storage dewar to the point of entry into the building. The parameters used in the calculation and the results were as follows:

<u>Variable</u>	<u>Value</u>	<u>Units</u>
w	4.229	lb / s
q	3566	scfm
D	1.097	in
p1	64.696	psia
p2	14.696	psia
Y	1	--
Py	0.773	--
K	53.166	--
Pg1	762.4	Kg/m ³
Pg2	1.138	Kg/m ³

The resistance coefficient; K, was computed for the piping that runs from the horizontal liquid nitrogen storage dewar to the CDF Assembly Hall. This consists of:

166 ft. of 1 in. schedule 10 straight pipe;
 10 ea. 1 in. 90 degree elbows;
 2 ea. 1 in. 45 degree elbows;
 1 in. valve, $C_v = 14$;
 1.5 in. valve, $C_v = 34$.

E.6. This section calculates the nitrogen flow rate into the CDF assembly hall assuming that the liquid nitrogen supply line ruptures at the point that it enters the CDF Assembly Building and Tank 32, the 3,000 gallon verticle liquid nitrogen storage dewar is on line. Method I, Section D.1 was used to determine the maximum flow of nitrogen gas into the CDF Assembly Hall. The major restriction to flow was considered to be the piping that brings the liquid nitrogen from the storage dewar to the point of entry into the building. The parameters used in the calculation and the results were as follows:

<u>Variable</u>	<u>Value</u>	<u>Units</u>
w	4.203	lb / s
q	3544	scfm
D	1.097	in
p1	64.696	psia
p2	14.696	psia
Y	1	--
Py	0.773	--
K	53.839	--
pg1	762.4	Kg / m^3
pg2	1.138	Kg / m^3

The resistance coefficient, K, was computed for the piping that runs from the vertical storage dewar to the CDF Assembly Hall. This consisted of:

75 ft. of 1 in. schedule 10 straight pipe;
 4 ea. 1 in. 90 degree elbows;
 0.75 in. valve, $C_v = 6.2$.

E.7 This section calculates the flow rate of nitrogen into the assembly hall through one of four control valves, PVLN, PVNI, or PVNS. It uses Method I, Section D.1 to determine the maximum flow of nitrogen. The restriction to flow is considered to be the piping from the nitrogen storage dewars described above and either the control valve; EVLN, EVNI, or EVNS. Each of the control valves has $C_v = 0.32$. The parameters used in the calculation and the results were as follows:

<u>Variable</u>	<u>Value</u>	<u>Units</u>
w	.274	lb/s
q	231	scfm
D	1.097	in
p1	64.696	psia
p2	14.696	psia
Y	1	--
Py	.773	--
K	12696.713	--
Pg1	762.4	Kg/m^3
Pg2	1.138	Kg/m^3

166 ft. of 1 in. schedule 10 straight pipe
 10 ea. 1 in. 90 degree elbows

2 ea. 1 in. 45 degree elbows
 1 in. valve, Cv = 14
 1.5 in. valve, Cv = 34
 0.156 in. valve, Cv = 0.32

E.8 Release of helium from the Low Beta Quad magnets.

The volume and flow of cryogenics given this event were supplied by the Accelerator Division and included in the D0 ODH analysis since the same magnets exist in the D0 Collision Hall.

- i) Each string contains 400 liters of liquid Helium at 2.3 atm (density = 150.8 Kg/m^3).
That is 13,103 scf.
- ii) Each string is supplied with 2020 liters/hour of liquid Helium at 2.3 atm.
That is 1,103 scfm.

Assumed Restriction to Flow: The Helium flow given above was determined for flow thru a control valve with Cv = 0.32 and inlet pressure of 3.5 atm, and either a JT valve with Cv = 0.5 or a liquid expansion engine with inlet conditions of 18 atm, 4.6 degK.

E.9 Release of nitrogen from the Low Beta Quad magnets.

The volume and flow of cryogenics given this event were supplied by the Accelerator Division and included in the DO ODH analysis since the same magnets exist in the DO Collision Hall.

- i) Each string contains 300 liters of liquid Nitrogen at 2.3 atm (density = 770.85 Kg/m^3).
That is 7,181 scf.
- ii) Each string is supplied with 1500 liters/hour of liquid Nitrogen at 2.3 atm.
That is 598 scfm.

Assumed Restriction to Flow: The Nitrogen flow is given for a control valve with Cv = 0.05 and inlet pressure of 3.5 atm.

E.10 Solenoid Magnet:

Contribution to the ODH Hazard:

- i) The Solenoid contains approximately 10 liters of liquid Nitrogen at 2.36 atm (density = 770.85 Kg/m^3) or 239 scf.
- ii) It also contains approximately 60 liters of liquid Helium at 1.48 atm (density = 18.70 Kg/m^3) or 244 scf.

E.11 Detector gas

Table 12 Detector Gas Flow Restrictions

Gas	Maximum Flow (scfm)	Restriction
Argon	22.6	Pressure Regulator (PRV-008) (@ 200 psig inlet)
Argon/CO ₂	52	18" of 1/2" flex tube
Argon/Ethane	7.56	Restricting Orifice (RO-005)

Table 13 . Test Room Gas Flow Restrictions

Gas	Maximum Flow (scfm)	Restriction
Argon/CO ₂	0.24	Excess Flow Valve
Argon/Ethane	0.26	Excess Flow Valve
Nitrogen	0.28	Excess Flow Valve

The gases used for the detector are limited in their delivery rates by the piping used in the systems. These rates are detailed in Table 6. The limits of delivery to the test rooms are listed in Table 12.

APPENDIX F. ASSEMBLY HALL FATALITY RATE DUE TO CRYOGENIC SYSTEM FAILURES

This section calculates the Fatality Rate due to the cryogenic system in the Assembly Hall with the solenoid in the Assembly Hall. If the ODH detection system detects low oxygen levels in the assembly hall then the roof exhaust louvers RE-7 are opened. When the roof exhaust louvers are open, the calculations take into account gravity induced natural ventilation of helium mixed with air rising through the louvers. If low oxygen levels are detected in the pit then the ODH detection system sends a signal to turn on the pit exhaust fan. P_{ODH} is the probability of the ODH detection system working properly.

The probability P_{Fans} is the likelihood of the pit purge fan not turning on when signaled to do so by the ODH detection system. If the pit exhaust fan is not operational, then it is assumed that there is no ventilation in the assembly hall. The pit exhaust fan is a benefit only in cases involving nitrogen leaks. In cases with helium leaks, the calculations assume no forced ventilation

Each subsections F.1 - F.10 deals with failures of a different part of the Assembly hall cryogenic system that cause ODH problems. For each case, P_{He-i} is the probability of a failure occurring that causes a significant release of helium. These sections also determine the Fatality rates defined in section 3. In subsection F.11, a summary table is provided and the Fatality rate for the entire assembly hall cryogenic system is determined. Subsection F.11 looks at the abnormal situation where the assembly hall cryogenic system is operating but the pit purge fan has failed and is known to have failed.

F.1 For this case consider a possible helium leak in the compressor discharge line between the point it enters the CDF Assembly Building and the star refrigerator. The calculations in Section E.1 determined the maximum helium flow into the Assembly Hall to be 20,334 scfm for this case. If the ODH detection system works properly, the roof exhaust dampers will open to vent this helium. Follow the method in Appendix C to calculate the steady state oxygen concentration when the roof exhaust RE-7 is open.

$$C = 144 \cdot (32.2) \cdot (0.0001617) \cdot (20,334 / 60) / ((32.2) \cdot (35) \cdot (400)) \\ = 0.1910$$

The solution to the cubic equation $x^3 + C \cdot x - C \cdot 1.16 = 0$, is $x = 0.5011$. The concentration of helium is 50.1% and therefore the concentration of oxygen = $0.21 \cdot (1 - 0.5011) = 0.1048$ or 10.48%. Therefore, we will set the Fatality Factors $F_{He-i} = F_{He-i, Fans} = 3 \times 10^{-2}$.

If the ODH detection system fails to open the roof exhaust dampers assume there is no ventilation and Fatality Factors, $F_{He-i, ODH} = 1.00$.

Next, find the probability P_{He-i} of a leak occurring in this section of piping using estimated mean failure rates from the Fermilab ES&H Manual.

Pipe (<3") ruptures	10^{-9} events/ h sect of pipe
with at most 3 sections considered for this failure	3×10^{-9} events/ h
Elbows and Tees rupture	10^{-9} / h /component
with 10 total elbows and tees	10^{-8} events/ h

The probability of a leak occurring for this case is $P_{He-i} = 1.3 \times 10^{-8}$ events/ h.

F.2 For this case there could be a helium leak in the in the high pressure side of the heat exchanger, expansion engine U-tubes, or the valve box. The calculations in section E.2 determined the maximum helium flow into the Assembly Hall to be 5,744 scfm. For when the ODH detection system opens the roof exhaust dampers RE-7, calculate the steady state oxygen concentration by the method in Appendix C for natural ventilation.

$$C = 144 \cdot (32.2) \cdot (0.0001617) \cdot (5,744 / 60)^2 / ((32.2) \cdot (35) \cdot (400)) \\ = 0.0152$$

The solution to the cubic equation $x^3 + C \cdot x - C \cdot 1.16 = 0$, is $x = 0.2408$. The concentration of helium is 24.1% and therefore the concentration of oxygen = $0.21 \cdot (1 - .2408) = 0.1594$ or 15.9%. Therefore, assign the Fatality Factors $F_{He-i} = F_{He-i,Fans} = 2 \times 10^{-6}$. If the ODH detection system fails then the roof exhaust dampers might not open, in which case, the Fatality Factors, $F_{He-i,ODH} = 1.00$.

Determine P_{He-i} from the heat exchanger Failure Rates given in the Fermilab ES&H Manual. These failure rates are from historical data on the Energy Saver refrigerator buildings including both accelerator and beam line refrigerators. There have been 35 heat exchangers operated 6 years and 1 heat exchanger operated 4 years without a major leak or rupture. Therefore, for 214 heat exchanger-years we have:

Failure Rate for Major Leak or Rupture in a Heat Exchanger	$7.7 \times 10^{-7} / \text{h}$
3 U-tubes involved are HUT-7, 9, 11.	
Failure Rate for 3 Fluid Lines -- Leak or Rupture	$9 \times 10^{-6} / \text{h}$

The event probability for a significant leak in this case is $P_{He-i} = 9.77 \times 10^{-6} / \text{h}$.

F.3 This case covers the likelihood of the relief valve SV-256-H on the valve box, at the outlet of the heat exchanger sticking open. The maximum flow rate was calculated in Section E.2 and is the same as for Section F.2. The fatality rates F_{He-i} , $F_{He-i,ODH}$, and $F_{He-i,Fans}$ are the same as in Section F.2. The Fermilab ES&H Manual lists an event probability $P_{He-i} = 10^{-5} / \text{h}$ for relief valve premature open.

F.4 If the helium storage dewar insulating vacuum space develops a vacuum leak and the relief valve SV-1802-H fails to open then the rupture disk RD-1802-H will open and release helium gas into the Assembly Hall. We will treat the release of the dewar contents as instantaneous. The volume of helium released will be,

$$\text{Vol.} = 2,000 \text{ liters ft}^3 / (28.3 \text{ liters}) (112 \text{ Kg} / \text{m}^3) / (0.1625 \text{ Kg} / \text{m}^3) \\ = 48,709 \text{ scf}$$

This instantaneous release is below the instantaneous helium release threshold of 88,000 scf (Appendix B) for an ODH condition, and therefore will not cause a problem.

However, after the initial release, the wet engine may continue to force helium into the dewar or helium flows through the valve PVJT into the dewar. The maximum throughput for the Fermilab Satellite Refrigerator Expansion Engines (report by Thomas Peterson) is 80 g/s or 1,043 scfm. This flow rate is below the continuous helium release rate threshold of 2,055 scfm (Appendix B), therefore $F_{He-i} = F_{He-i,Fans} = 0.00$. If the ODH detection system fails to open the roof exhaust dampers then Fatality Factor is $F_{He-i,ODH} = 1.00$.

Refer to the Fermilab ES&H Manual for individual component failure rates.

Dewar leak or rupture	$10^{-6} / \text{h}$
Relief value failure to open	$10^{-5} / \text{h}$

For this case there must be a leak into the vacuum space and a relief valve must fail to open so that event probability $P_{He-i} = 10^{-11} / \text{h}$

F.5 Consider a possible rupture of U-tube HUT-3 which would suddenly dump the contents of the helium dewar into the Assembly Hall. After the initial venting of the dewar contents, there could possibly be a steady flow of helium into the assembly hall from either the wet engine or the valve PVJT. This is very similar to case F.4 and the fatality factors are the same. As per the Fermilab ES&H Manual, for a cryogenic fluid line leak or rupture, the event probability is $P_{He-i} = 3 \times 10^{-6} / \text{h}$

F.6 Look at the case when a relief valve sticks open when the detector is located in the Assembly Hall. The relief valves first considered are all associated with flow from the helium storage dewar and are rated for 100 scfm of air. This applies to the following relief valves:

SV-257-H on the valve box.
SV-254-H on the valve box.
SV-1010-H on the control dewar.
SV-1602-H on the Assembly Hall transfer line from the helium dewar to the control dewar.

Helium flow into the Assembly Hall was calculated to be 376.3 scfm in section E.3. For when the roof exhaust dampers open, calculate the steady state oxygen concentration by the method in Appendix C.

$$C = 144 * (32.2) * (0.0001617) * (2.836 / 60)^2 / ((32.2) * (35) * (400)) \\ = 0.0037$$

The solution to the cubic equation $x^3 + C*x - C*1.16 = 0$, becomes $x = 0.1554$. This indicates that the concentration of helium is 15.5% and therefore the concentration of oxygen = $0.21 * (1 - 0.1554) = 0.1774$ or 17.7%. This concentration is greater than we got when considering the effect of the air handler alone. Therefore, we will assume the Fatality Factors $F_{He-i} = F_{He-i,Fans} = 10^{-7}$. If the ODH detection system fails to open the roof exhaust assume Fatality Factors, $F_{He-i,ODH} = 1.00$.

The Fermilab ES&H Manual provides an estimated Mean Failure Rate of 10^{-5} / h for a relief valve prematurely opening. Failure Rates: For one of four relief valves prematurely opening the event Probability $P_{He-i} = 4 \times 10^{-5}$ / h.

F.7 Consider a possible rupture or leak in one of the following components when the detector is in the Assembly Hall:

- i) The suction header
- ii) Low pressure side of the heat exchanger, or valve box.
- iii) The transfer line helium return.
- iv) Control dewar
- v) U-tubes HUT-2, 6, 10.
- vi) U-tubes HUT-1, 8 (neglecting restriction to flow due to PVBY)
- vii) Relief valve SV-1013-H sticks open.

The release rate for this failure, calculated in section E.4 as 1,514 scfm is below the instantaneous and continuous helium rate threshold limits of Appendix B and therefore $F_{He-i} = F_{He-i,Fans} = 0.00$. The only time a problem would exist is when the ODH detector system fails to open the roof exhaust. The Fatality Factors, $F_{He-i,ODH} = 1.00$ are assumed.

The Failure Rates for the individual components, listed below, are based on the Estimated Mean Failure Rates given in the Fermilab ES&H Manual. The heat exchanger Failure Rates are given for the Energy Saver refrigerator buildings. These include both the Accelerator and beamline refrigerators.

i)	The suction header	
	Fluid Line (Cryogenic) Leak or Rupture	3×10^{-6} / h
ii)	Low pressure side of the heat exchanger, or valve box.	
	Cold Box, Expanders, Valve Box System, as in F.2	9.77×10^{-6} / h
iii)	The transfer line helium return.	
	Fluid Line (Cryogenic) Leak or Rupture.	3×10^{-6} / h
iv)	Control dewar	
	Dewar Leak or Rupture	10^{-6} / h
ii)	U-tubes HUT-2,6,10.	
	Fluid Line (Cryogenic) Leak or Rupture	3×10^{-6} / h

iii) U-tubes HUT-1, 8 (neglecting restriction due to EVBY)

Fluid Line (Cryogenic) Leak or Rupture $3 \times 10^{-6} / \text{h}$

iv) Relief valve SV-1013-H sticks open.

Relief valve premature open $10^{-5} / \text{h}$

Event Probability $P_{He-i} = 3.28 \times 10^{-5} / \text{h}$

Note: The probability of a rupture in the control dewar or transfer line increases when you consider the possibility of one of the quench relief valves failing to open when a quench occurs. If you assume that a rupture will occur if one of the three relief valves fails to operate during a quench, the failure rate for the event, E', that either the control dewar ruptures or the transfer line ruptures is as follows:

$P(E') = P(E' | Q) * P(Q) + P(E' | \text{not } Q) * P(\text{not } Q)$ where

$P(Q) = \text{probability of a quench} = 10^{-1} \text{ D/h}$

$P(\text{not } Q) = 1 - P(Q) = 0.9$

$P(E' | Q)$ = probability that either the control dewar or the transfer line ruptured given that a quench has just occurred
 = probability that one of the three relief valves failed given that a quench has just occurred
 = $3 \times 10^{-5} \text{ D}$

$P(E' | \text{not } Q)$ = probability that either the control dewar or the transfer line ruptures given that a quench has not just occurred
 = $3 \times 10^{-6} / \text{h} + 10^{-6} / \text{h} = 4 \times 10^{-6} / \text{h}$

Therefore $P(E') = 6.6 \times 10^{-6} / \text{h}$

and the adjusted $P_{He-i} = 9.256 \times 10^{-4} / \text{h}$

F.8. This case considers the rupture of the liquid nitrogen supply line at the point that it enters the CDF Assembly Building with the Tank 18, the 13000 gallon horizontal liquid nitrogen storage dewar on line. Section E.5 calculates the nitrogen flow into the Assembly Hall to be 3,566. For any release of nitrogen we must consider the operation of the Pit area purge fan in determining the oxygen concentration. The Pit area purge fan draws air and/or nitrogen out of the pit at a rate of 10,700 scfm. Method VII of Section D.7 results in an oxygen concentration of 14.00% which gives a Fatality Factor, $F_{He-i} = 6 \times 10^{-5}$.

For the case where the ODH detection system fails to detect an existing ODH condition, or the ventilation system fails to go into emergency ODH mode, we assume Fatality Factors, $F_{He-i, ODH} = F_{He-i, Fans} = 1.00$. The event probability of this failure is the Estimated Mean Failure Rate is given in the Fermilab ES&H Manual, or $P_{He-i} = 3 \times 10^{-6} / \text{h}$.

F.9 This case considers the rupture of the liquid nitrogen supply line at the point that it enters the CDF Assembly Building with the Tank 32, the 3000 gallon vertical liquid nitrogen storage dewar on line. Section E.6 calculates the nitrogen flow into the Assembly Hall to be 3,544. For any release of nitrogen we must consider the operation of the Pit area purge fan in determining the oxygen concentration. The Pit area purge fan draws air and/or nitrogen out of the pit at a rate of 10,700 scfm. Method VII of Section D.7 results in an oxygen concentration of 14.04% which gives a Fatality Factor, $F_{He-i} = 6 \times 10^{-5}$.

For the case where the ODH detection system fails to detect an existing ODH condition, or the ventilation system fails to go into emergency ODH mode, we assume Fatality Factors, $F_{He-i, ODH} = F_{He-i, Fans} = 1.00$. The event probability of this failure is the Estimated Mean Failure Rate is given in the Fermilab ES&H Manual, or $P_{He-i} = 3 \times 10^{-6} / \text{h}$.

F.10 This case considers the release of nitrogen in the Assembly Hall due to a rupture in the heat exchanger, transfer line to the solenoid or a rupture at the solenoid, or one of the following four relief valves sticking open:

SV-1604-N
SV-1605-N
SV-1606-N
SV-1015-N

The release rate for this failure is 231 scfm of nitrogen as calculated in section E.6. When the oxygen monitors detect the rupture, the pit purge fan will be energized. Method VII in Section D.7 determines that the steady state oxygen concentration to be 20.5%. Therefore $F_{He-i} = 0.00$ and it is assumed that $F_{He-i,ODH} = F_{He-i,Fans} = 1.0$.

The following Failure Rates are given in the Fermilab ES&H Manual are applied to this case:

- i) The nitrogen heat exchanger
Nitrogen heat exchanger $7.7 \times 10^{-7} / \text{h}$
- ii) The transfer line supplying nitrogen to the solenoid.
Fluid Line (Cryogenic) Leak or Rupture $3 \times 10^{-6} / \text{h}$
- iii) Nitrogen lines in the solenoid.
Fluid Line (Cryogenic) Leak or Rupture $3 \times 10^{-6} / \text{h}$
- iv) Relief Valve failure (sticks, or opens prematurely) $10^{-5} / \text{h}$

The event probability of this failure case is $P_{He-i} = 1.68 \times 10^{-5} / \text{h}$

F.11 Detector Gas Systems

- 1. Assembly Hall Fatality Rate contributions with normal ventilation.

In the event of a severed gas line for any of the chamber gas systems, the fatality rate will be clearly remain 0 so long as the ODH and ventilation systems remain operational. We will take the probability of completely severing a gas delivery pipe to be 5E-09.

The fatality factors for the double failure of piping and can be taken to be 1, simply to reduce the discussion to becoming trivially conservative. We then have the factors listed in Table 13 that feed into the overall fatality rate calculation:

Table 14 Detector Gas contributions to the Fatality Rate Calculation

Factor	Argon	Argon/CO2	Argon/Ethane
F_{gas}	0	0	0
$F_{ga,ODHs}$	1	1	1
$F_{gas,Fans}$	1	1	1
P_{gas}	5E-09	5E-09	5E-09

We note that these same fatality factors and probabilities apply to the case of the test rooms as well.

F.12 This case considers the SUVA notch phase separator relief valve sticking open or piping rupture. The relief valve will have the highest flow rate. The following Failure Rates are given in the Fermilab ES&H Manual are applied to this case:

- i) Notch phase separator relief valve

	Premature opening	$10^{-5} / \text{h}$
ii)	Storage vessel relief valve Premature Opening	$10^{-5} / \text{h}$
iii)	Piping rupture All Fluid Lines (no more than 100 joints)	$100 \times 10^{-9} / \text{h}$

The event probability of this failure case is $P_{He-i} = 2 \times 10^{-5} / \text{h}$

The set point is 350 psig and the normal operating pressure is 198 psig. The capacity at the normal set point is 165 SCFM of vapor or 30.7 GPM (1450 SCFM) of liquid. Method VII in Section 7.7 determines that the steady state oxygen concentration to be 18.1% with the pit purge fan running. Therefore $F_{SUVA} = 0.0$.

For the case of the ODH system not responding, or the fans not operating simultaneously with a SUVA release, the worst case is considered to be even mixing in the lower five feet of the pit. Method VIII in section 7.8 determines that the oxygen concentration would be 13.1%. A partial pressure of 96.9 mm produces a fatality factor $F_{SUVA-Fans} = F_{SUVA-ODH} = 6.5 \times 10^{-4}$.

APPENDIX G. COLLISION HALL: CRYOGENIC SYSTEM AND GAS SYSTEM FATALITY RATES

G.1 A relief valve sticks open when the detector is located in the Collision Hall:

The relief valve SV-1010-H on the control dewar is associated with flow from the helium storage dewar and is rated for 100 scfm of air. Helium flow into the Collision Hall was calculated to be 2,836 scfm. This rate exceeds the threshold limit, therefore, we must consider the operation of the air handling system in determining the oxygen concentration. The system of air handlers for the Collision Hall forces fresh air into the space at a rate of 34,000 scfm. Using Method VI, we find that the steady state concentration of oxygen will be 19.38%. This gives us a Fatality Factor, $F_{He-i} = 0$. If the air handling system is on emergency power the capacity is reduced to 17,000 scfm, the steady state concentration of oxygen will be

18.000/c. This gives us a Fatality Factor, $F_{He-I,Fans} = 6 \times 10^{-8}$

For the case where the ODH detection system and/or the air handling system fails we assume $F_{He-I,ODH} = 1.00$

Failure Rates: The following Failure Rate is given in the Fermilab ES&H Manual.

i) Relief valve premature open $10^{-5} / \text{h}$

Event Probability $P_{He-i} = 10^{-5} / \text{h}$

G.2 Rupture or leak in the transfer line helium return or the control dewar when the detector is located in the Collision Hall:

Helium flow into the Collision Hall was calculated to be 1.514 scfm. This rate exceeds the threshold limit, therefore, we must consider the ODH mode operation of the air handling system in determining the oxygen concentration. The system of air handlers for the Collision Hall force fresh air into the space a rate of 34,000 scfm. Using Method VI, we find that the steady state concentration of oxygen will be 20.10%. This gives us a Fatality Factor, $F_{He-i} = 0$.

When the ventilation system is on emergency power due to a power outage, in the emergency ODH mode the ventilation system forces 17,000 scfm fresh air into the Collision Hall. Using Method VI, we find that the steady state concentration of oxygen will be 19.28%. This gives us a Fatality Factor, $F_{He-I,Fans} = 0$.

If the ODH detection system fails to detect an existing ODH condition the ventilation system will not go into emergency ODH mode we assume Fatality Factors, $F_{He-I,ODH} = 1.00$. For the case where the air handling system fails completely we assume $F_{He-I,Fans} = 1.00$.

Failure Rates: The following Estimated Mean Failure Rates are given in the Fermilab ES&H Manual.

i) The transfer line helium return.

Fluid Line (Cryogenic) Leak or Rupture $3 \times 10^{-6} / \text{h}$

ii) Control dewar

Dewar Leak or Rupture $10^{-6} / \text{h}$

Event probability $P_{He-i} = 4 \times 10^{-6} / \text{h}$

Note: The probability of a rupture in the control dewar or transfer line increases when you consider the possibility of one of the quench relief valves failing to open when a quench occurs. If you assume that a rupture will occur if one of the three relief valves fails to operate during a quench, the failure rate for the event, E', that either the control dewar ruptures or the transfer line ruptures is as follows:

$P(E') = P(E' | Q) \cdot P(Q) + P(E' | \text{not } Q) \cdot P(\text{not } Q)$ where

$P(Q) = \text{probability of a quench} = 10^{-1} \text{ D/h}$

$P(\text{not } Q) = 1 - P(Q) = 0.9$

$P(E' | Q) = \text{probability that either the control dewar or the transfer line ruptured given that}$

a quench has just occurred
 = probability that one of the three relief valves failed given that a quench has just occurred
 $= 3 \times 10^{-5} / D$

$P(E' \text{ not } Q)$ = probability that either the control dewar or the transfer line ruptures given that a quench has not just occurred
 $= 3 \times 10^{-6} / h + 10^{-6} / h = 4 \times 10^{-6} / h$

Therefore $P(E') = 6.6 \times 10^{-6} / h$

and the adjusted $P_{He-i} = 6.6 \times 10^{-6} / h$

G.3 Release of nitrogen due to a rupture in the transfer line to the solenoid or a rupture at the solenoid. Or the sticking open of relief valve SV-1015-N.

The release rate for this failure is 231 scfm. Using Method VII, we find that the steady state concentration of oxygen will be 20.85% when the air handler is not on emergency power ($F_{He-i} = 0.00$) and a concentration of 20.72% when it is ($F_{He-I,Fans} = 0.00$).

The only time that there would be a problem would be when the ODH detection system fails or the air handling system fails completely. For these cases we assume Fatality Factors $F_{He-I,ODH} = 1.00$.

Failure Rates: The following Failure Rates are given in the Fermilab ES&H Manual.

i) The transfer line supplying nitrogen to the solenoid.

Fluid Line (Cryogenic) Leak or Rupture $3 \times 10^{-6} / h$

ii) Nitrogen lines in the solenoid.

Fluid Line (Cryogenic) Leak or Rupture $3 \times 10^{-6} / h$

Event Probability $P_{He-i} = 6 \times 10^{-6} / h$

G.4 Release of helium from the Low Beta Quad magnets.

The volume and flow of cryogenics given this event were supplied by the Accelerator Division and included in the D0 ODH analysis since the same magnets exist in the D0 Collision Hall.

The instantaneous and continuous releases were determined to be:

Instantaneous release of helium 13,103 scf at 1 atm, 300 degK.

Continuous release of helium 1,103 scfm.

The instantaneous release is below the threshold limit. If the normal ventilation goes into the ODH mode (34,000 scfm fresh air) the steady state concentration of oxygen using Method VII becomes 20.34% for the continuous helium release. If the ventilation is on emergency power (17,000 scfm fresh air) this concentration would be 19.72%. The Fatality Factors are $F_{He-i} = F_{He-I,Fans} = 0.00$

The only time that there would be a problem would be when the ODH detection system and/or the air handling system fails. For these cases we assume the Fatality Factors $F_{He-I,ODH} = 1.00$.

Failure Rates: The Failure Rate for the Low Beta Quad magnets has been computed in the D0 Collision Hall ODH Analysis from information provided by the Accelerator Division.

i) Helium release.

For 4 magnets (2 magnets from each string) $4 \times 10^{-6} / h = 4 \times 10^{-6} / h$

Event Probability $P_{He-i} = 4 \times 10^{-6} / h$

G.5 Release of nitrogen from the Low Beta Quad magnets.

The volume and flow of cryogenics given this event were supplied by the Accelerator Division and included in the D0 ODH analysis since the same magnets exist in the D0 Collision Hall.

The instantaneous and continuous releases were determined to be:

Instantaneous release of nitrogen 7,181 scf.

Continuous release of nitrogen 598 scfm.

The instantaneous release is below the threshold limit. If the normal ventilation goes into the ODH mode (34,000 scfm fresh air) the steady state concentration of oxygen using Method VII becomes 20.64% for the continuous nitrogen release. If the ventilation is on emergency power (17,000 scfm fresh air) this concentration would be 20.29%. The Fatality Factors are $F_{He-i} = F_{He-I,Fans} = 0.00$. The only time that there would be a problem would be when the ODH detection system and/or the air handling system fails. For these cases we assume the Fatality Factors $F_{He-I,ODH} = 1.00$.

Failure Rates: The Failure Rate for the Low Beta Quad magnets has been computed in the DO Collision Hall ODH Analysis from information provided by the Accelerator Division.

i) Nitrogen release.

For 4 magnets (2 magnets from each string) $4 \times 10^{-9} / \text{h} = 4 \times 10^{-9} / \text{h}$

Event Probability $P_{He-i} = 4 \times 10^{-9} / \text{h}$

G.6 Detector Gas Systems

In the event of a severed gas line for any of the chamber gas systems, the fatality rate will be clearly remain 0 so long as the ODH and ventilation systems remain operational. We will take the probability of completely severing a gas delivery pipe to be 5E-09.

The fatality factors for the double failure of piping and ventilation can be taken to be 1, simply to reduce the discussion to becoming trivially conservative. The fatality rate factors are identical to the Assembly Hall case, and are listed in Table 13. It should be noted that the delivery system of detector gas prevents delivery of gas at the full flow rate of the main supply pipes to the collision hall, due to the safety bubblers on the gas distribution system. These limit the back pressure of the supply to about 1 inch of oil. For this reason, the maximum delivery to the collision hall is much reduced from the values in Table 6.

G.7 SUVA release

This case considers the release of the SUVA refrigerant due to a rupture in one of the delivery lines. There are no relief valves discharging into the collision hall. As in Appendix F.12, the steady state flow into the hall is potentially 1450 SCFM, well above the threshold level for continuous release into the collision hall. A release would trigger the ODH response, engaging the 17,000 CFM (at least) ventilation fans. By method VII, App. D.2.2, the steady state oxygen concentration would become 19.2%, corresponding to $F_{SUVA} = 0.0$.

The following Failure Rates are given in the Fermilab ES&H Manual are applied to this case:

i) Piping rupture

All Fluid Lines (no more than 100 joints) $100 \times 10^{-9} / \text{h}$

The event probability of this failure case is $P_{SUVA} = 1 \times 10^{-7} / \text{h}$

We will take the fatality factors for simultaneous failure of the SUVA system with the ventilation or ODH systems to be
 $F_{SUVA-Fans} = F_{SUVA-ODH} = 1.0$

Appendix H: SIZING AND OPERATION OF THE 1/4 HP EXHAUST FANS

The Assembly and Collision Halls are each equipped with a 1/4 hp exhaust fan, identified as EF1 and EF2. The purpose of these exhaust fans is to ensure the sufficient introduction of fresh air to compensate for the inerting gas from the detector. These fans only perform the desired function when the main ventilation fans are on and mixing the atmosphere within the halls.

The total flammable gas flow to the detector is 170 scfh and the non-flammable gas flow is 1,875 scfh. The cryogenics system contributes 540 scfh of non-flammable gas. If we assume a total failure of the flammable gas recovery system, then the total inerting flow is 2,585 scfh (43 scfm). The required exhaust flow rate to compensate for the detector inerting is

$$\text{Cooxygen} = 0.21 (\text{qexhaust} - \text{qinerting}) / \text{qexhaust} = 0.18 = 0.21 (\text{qexhaust} - 43 \text{ scfm}) / \text{qexhaust} \quad (1)$$

solving for qexhaust

$$\text{qexhaust} = 301 \text{ scfm}$$

The exhaust ducts are equipped with flow measuring devices that send a flow signal to the FESS ventilation computer. Louvers will be used to control the exhaust flow rate within an operating band. The exhaust system has a design flow rate of 700 scfm and will alarm at 350 scfm. This 350 scfm alarm starts a timer that will evacuate the appropriate hall(s) after a continuous alarm for 4 hours. The FESS ventilation computer will use signals from alarm relay circuits to determine the location of the detector. Only a low exhaust flow rate signal from the hall containing the detector can initiate an evacuation alarm. Failure of these fans will generate an ODH condition in a length of time calculated in App. B.3 and B.4.

References

- 1 Fermilab ES&H Manual Section 5064 TA.
- 2 DO Engineering Note EN-3740.510-229
- 3 (Reactor Safety Study; An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants: Failure Data; U.S. Nuclear Regulatory Commission/DOC)